

AAMRL-TR-90-062

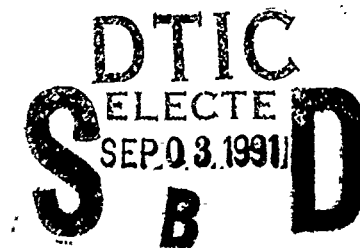
AD-A240 288



**PHYSICOCHEMICAL PROPERTIES AND
DISSOLUTION IN SIMULATED BIOLOGICAL FLUIDS
OF PARTICLES OF BERYLLIUM-POWERED ROCKET
MOTOR EXHAUST AND PURE BERYLLIUM OXIDES
CALCINED AT LOW AND HIGH TEMPERATURE**

E. C. Kimmel
S. A. Howe
W. T. Brashear

NSI TECHNOLOGY SERVICES CORPORATION
P.O. BOX 31009
DAYTON, OH 45431-0009



R. L. Carpenter

NAVAL MEDICAL RESEARCH INSTITUTE/TOXICOLOGY DETACHMENT
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-6573

DECEMBER 1990

FINAL REPORT FOR THE PERIOD AUGUST 1987 - JULY 1990

Approved for public release; distribution is unlimited.

91-09394



HARRY G. ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY
HUMAN SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6573

91 9 3 00 3

NOTICES

When U S Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Please do not request copies of this report from the Harry G. Armstrong Aerospace Medical Research Laboratory. Additional copies may be purchased from:

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

Federal Government agencies and their contractors registered with Defense Technical Information Center should direct requests for copies of this report to:

Defense Technical Information Center
Cameron Station
Alexandria, Virginia 22314

TECHNICAL REVIEW AND APPROVAL

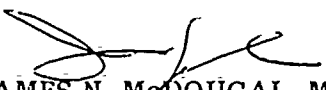
AAMRL-TR-90-062

The experiments reported herein were conducted according to the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animal Resources, National Research Council.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER


JAMES N. McDOUGAL, Maj, USAF, BSC
Deputy Director, Toxic Hazards Division
Harry G. Armstrong Aerospace Medical Research Laboratory

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE DECEMBER 1990	3. REPORT TYPE AND DATES COVERED Final Report, August 1987 - July 1990	
4. TITLE AND SUBTITLE Physicochemical Properties and Dissolution in Simulated Biological Fluids of Particles of Beryllium Powered Rocket Motor Exhaust and Pure Beryllium Oxides Calcined at Low and High Temperature		5. FUNDING NUMBERS PE 62202F PR 6302 TA 630201 WU 63020174 Accession No	
6. AUTHOR(S) E. Kimmel, S. Howe, W. Brashear, R. Carpenter			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NSI Technology Services Corporation P.O. Box 31009 Dayton, OH 45431-0009		8. PERFORMING ORGANIZATION REPORT NUMBER AAMRL-TR-90-062	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) AAMRL/Toxic Hazards Division HSD/AFSC Wright-Patterson AFB, OH 45433-6573		10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES			
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.		12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) Certain physicochemical characteristics and dissolution properties, in simulated biological fluids, of Beryllium powered rocket motor exhaust (RME) particles were compared to those of pure Beryllium oxide (BeO - the major component of RME) calcined at either 550 or 1600 °C. The purpose of these comparisons was to determine which of the forms of BeO had physical and dissolution characteristics most similar to RME, thereby providing a preliminary basis for estimation of the potential toxicity of RME and to determine which form of BeO might be best suited as a surrogate for RME in future studies. RME is very scarce and difficult, as well as costly, to obtain. Though not definitive, this investigation suggests that the physical structure and dissolution properties of RME particles may be most similar to those of BeO calcined at the lower temperatures, which is widely held to be the most toxic of the BeO species.			
14. SUBJECT TERMS Beryllium oxide particles Serum ultrafiltrate solubility		High- and low-temperature calcined Rocket motor exhaust	15. NUMBER OF PAGES 26
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UI.

PREFACE

This is one of a series of technical reports describing the results of experimental laboratory programs at the Toxic Hazards Research Unit, NSI Technology Services Corp. This document serves as the final report on a comparison of the physicochemical and dissolution properties of Beryllium-powered rocket motor exhaust particles with those properties of pure Beryllium particles calcined at low and high temperature. The research described herein began in August of 1987, was suspended in September of 1988 (per sponsor request), reinstituted in March of 1990, and completed in July of 1990 under U.S. Air Force Contract No. F33615-85-C-0532. Dr. Melvin E. Andersen, Lt Col Harvey Clewell, III, USAF, and Lt Col Michael B. Ballinger, USAF, all served at various times as Contract Technical Monitor for the U.S. Air Force, Harry G. Armstrong Aerospace Medical Research Laboratory during the conduct of this investigation.



Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC B	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution/	
Availability Codes	
Dist A-1	Avail and/or Special

TABLE OF CONTENTS

SECTION	PAGE
PREFACE	1
LIST OF FIGURES	3
LIST OF TABLES	4
ABBREVIATIONS	5
1 INTRODUCTION	7
2 MATERIALS AND METHODS	8
BeO AND RME SAMPLES	8
SAMPLE PREPARATION	8
DISSOLUTION KINETICS	9
STATISTICS	9
3 RESULTS	12
BeO AND RME CHEMICAL COMPOSITION	12
PARTICLE MORPHOLOGY	12
DISSOLUTION KINETICS	15
4 DISCUSSION	19
REFERENCES	20
QUALITY ASSURANCE STATEMENT	22

LIST OF FIGURES

FIGURE	PAGE
1 Experimental Apparatus used for Determination of Particle Dissolution Kinetics	10
2 Electron Photomicrographs of LF BeO, RME, and HF BeO Particles	14
3 Time Course of Fractional (Cumulative) Dissolution of LF BeO in SUF: Two Samples	16
4 Time Course of Fractional (Cumulative) Dissolution of HF BeO in SUF: Two Samples	17
5 Time Course of Fractional (Cumulative) Dissolution of RME in SUF: Single Sample	18

LIST OF TABLES

TABLE	PAGE
1 COMPOSITION OF BLOOD PLASMA AND LUNG FLUID SIMULANT	11
2 TRACE ELEMENT COMPOSITION OF LOW- AND HIGH-TEMPERATURE CALCINED BERYLLIUM OXIDE .. .	13
3 ELEMENTAL COMPOSITION OF ROCKET MOTOR EXHAUST PARTICLE SAMPLES BY SPARK SOURCE MASS SPECTROSCOPY .. .	13
4 ELEMENTAL COMPOSITION OF ROCKET MOTOR EXHAUST PARTICLE SAMPLES BY ATOMIC ABSORPTION .. .	14
5 PARTICLE MORPHOLOGY .. .	14
6 PARTICLE DISSOLUTION KINETICS .. .	18

ABBREVIATIONS

AA	Atomic absorption
AAMRL	Armstrong Aerospace Medical Research Laboratory
ACGIH	American Conference of Governmental Industrial Hygienists
Al	Aluminum
B	Boron
Be	Beryllium
BeO	Beryllium oxide
BET	Brunauer-Emmett-Teller surface area analysis
°C	Degrees Celsius
Cl	Chlorine
cm	Centimeter
cm ²	Square centimeter
cm ³	Cubic centimeter
CMD	Count median diameter
ECD	Electron capture detection
Fe	Iron
g	Gram
HF BeO	High-fired beryllium oxide (1600 °C)
h	Hour
K	Potassium
k	Dissolution rate constant
L	Liter
LF BeO	Low-fired beryllium oxide (550 °C)
M	Mass remaining at time t
M ₀	Initial mass at time 0

Mg	Magnesium
Mn	Manganese
MMAD	Mass median aerodynamic diameter
MMD	Mass median diameter
m	Fractional dissolution rate
m ²	Square meter
mg	Milligram
min	Minute
mL	Milliliter
mM	Millimole
NIST	National Institute for Standards and Technology
P	Phosphorus
ppm	Parts per million
RME	Rocket motor exhaust
Si	Silicon
Sp	Specific surface area
SSMS	Spark source mass spectroscopy
SUF	Serum ultrafiltrate
wt	Weight
σ_g	Geometric standard deviation
μm	Micrometer

SECTION 1

INTRODUCTION

U.S. Air Force fuel research and development programs have found Beryllium (Be)-bearing materials to have excellent potential as high efficiency solid propellants for rocket motors. However, rocket motor exhaust (RME) particles have been found to contain beryllium oxide (BeO, CAS No. 1304-56-9) and traces of metallic Be (CAS No. 7440-41-7). Both of these substances, in pure form, have been shown in epidemiologic and experimental studies to produce a variety of toxic responses, and both are suspect carcinogens (Hardy and Tabershaw, 1946; Sanders et al., 1975; Wagoner et al., 1980; Hart et al., 1984). Of the two primary potential routes of exposure to Be compounds (oral and inhalation), only the inhalation route is considered to pose a significant threat at environmentally relevant concentrations (Callahan, 1979). The toxic potency of BeO particles has been demonstrated to be a function of the physical properties of the particles, which, in turn, are a function of the temperature at which the particles are calcined. The toxicity of BeO aerosol particles apparently is directly proportional to their solubility, which is directly proportional to the calcination temperature (Spencer et al., 1968; Eidson et al., 1984; Finch et al., 1988a). Neither the physicochemical properties nor the toxicity of RME particles have been determined. The present investigation was undertaken to compare the chemical, physical, and dissolution characteristics of RME residue with those of particles of BeO calcined at low and high temperatures and to provide preliminary information useful for the design of studies to assess toxicity of RME. Due to the scarcity of RME, said comparisons should indicate which form of BeO might best be suited as a surrogate (if necessary) for RME in future toxicity studies.

SECTION 2

METHODS AND MATERIALS

BeO AND RME SAMPLES

Samples of pure BeO calcined at 550 °C (low fired [LF BeO]) and 1600 °C (high fired [HF BeO]) – both white in color – were obtained commercially (Brush Wellman Inc., Elmore, OH) for this investigation. Analysis of trace elements found in the BeO samples was provided by the supplier. Ten small samples of RME (light gray to black in color) were provided through the AAMRL/TH by Morton Thiokol, Inc. (Elkton, MD). Portions of each sample of RME were used for spark source mass spectroscopic (SSMS) and atomic absorption (AA) analyses to determine elemental composition (Accu-Labs Research, Inc., Wheatridge, CO). Because of the limited mass of individual RME samples, all but two of the samples were pooled for further investigation.

SAMPLE PREPARATION

The RME material was received in the form of scrapings from various components of the RME manifold and associated parts of the motor test apparatus located in the motor exhaust plume. These materials ranged from coarse granules to relatively large (1- to 2-cm²) flakes. Because one of the original objectives of this project was to conduct inhalation toxicity studies with respirable-size aerosols of the RME as well as LF and HF BeO (Carpenter et al., 1989), the RME, as received, was clearly unsuitable for further experimentation. Likewise, preliminary electronmicroscopic examination of the LF and HF BeO powders as received showed that both materials had a count median diameter (CMD) in excess of 300 μ m (Carpenter et al., 1989). Thus, the LF and HF BeO samples were clearly beyond respirable size range and therefore also unsuitable for inhalation toxicity studies. Consequently, samples of all three test materials were pulverized using an air-impact mill (Trost Model 1047, Colt Industries, Newtown, PA) to reduce particle size to the respirable range. Representative particles of pulverized materials were dispersed on electron microscope planchets for optical determination of particle size. Automated image analysis (C-R Research Image Analyzer, Olympus Corp., Mountainview, CA) of electron micrographs of samples of each of the test materials was used to determine the CMD (based on Ferret's diameter for irregularly shaped particles – Hinds, 1982) and geometric standard deviation (σ_g) of the particle size distribution. Two hundred fifty to 300 particles selected at random were used to make these determinations for each material tested. The mass median diameter (MMD) of the particles was calculated using Hatch-Choate equations (Hatch and Choate, 1929; Raabe, 1970) and the mass median aerodynamic diameter (MMAD) of the particles was calculated by multiplying the MMD by the square root of the particle density (Willeke and Baron, 1990). The specific surface area (Sp) of pulverized test materials was determined by

5-point Brunauer-Emmett-Teller (BET) analysis of nitrogen absorption isotherms (Rothenberg et al., 1982) and the absolute density of the particles was determined by helium pycnometry (Ricera, Inc., Analytical Services, Painesville, OH).

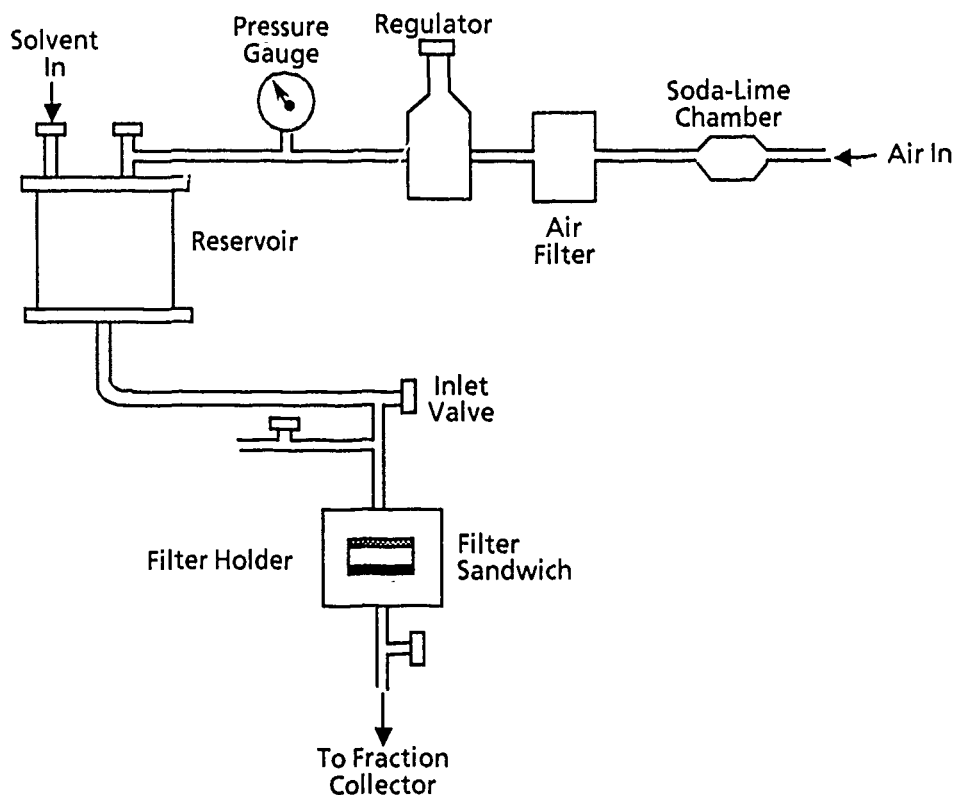
DISSOLUTION KINETICS

Particle solubility was determined by a method similar to that of Moss and Kanapilly (1980). Figure 1 illustrates the experimental apparatus and flowpast filter holders used in this investigation. Approximately 50 mg of test material was suspended on a filter which was then sealed in a filter holder. The filter holders were submerged and maintained in a constant temperature bath (37 °C) throughout the experiment. Simulated biological fluid - serum-ultrafiltrate (SUF) (see Table 1 for composition) at 37 °C was metered through the filter assembly continuously for approximately 800 h at a rate of 0.32 mL/min. The SUF solution was treated with streptomycin and penicillin G to retard microbial growth in the media. Duplicate filter assemblies were prepared for both LF and HF BeO; however, due to the limited quantity of RME available and the anticipated requirements for impending inhalation studies with RME, only one filter assembly was prepared for this test material. Daily samples taken from the fraction collector for each filter assembly were analyzed for Be (hence BeO) content in the SUF-filter eluants. Initially, the amount of BeO dissolved daily was determined by a method previously developed at AAMRL (Taylor and Arnold, 1969) involving chelation of Be with trifluoroacetylacetone and subsequent gas chromatography with electron capture detection (ECD). However, transport of water through the sample preparation process degraded the chromatograph column, making repeated measurement via this method difficult and inconclusive (Carpenter et al., 1989). Consequently, a Be wavelength specific, AA method was developed to analyze Be (hence BeO) content in the SUF samples. Calibrations were prepared by analysis of serial dilutions of a commercially obtained (Fisher Scientific, Cincinnati, OH) 1000 ppm Be National Institute for Standards and Technology (NIST)-certified standard reference material.

STATISTICS

Comparison of the physicochemical properties and dissolution kinetics of RME with those of LF and HF BeO were performed using discrimination and classification analysis methods (Johnson and Wichern, 1988). A linear vector scale, based on pooled variances of several comparable measurement factors, was used to determine statistically significant similarity of RME characteristics (dependent variable) with either LF BeO or HF BeO characteristics (independent variables).

EXPERIMENTAL ARRANGEMENT



PARALLEL FLOW FILTER HOLDER

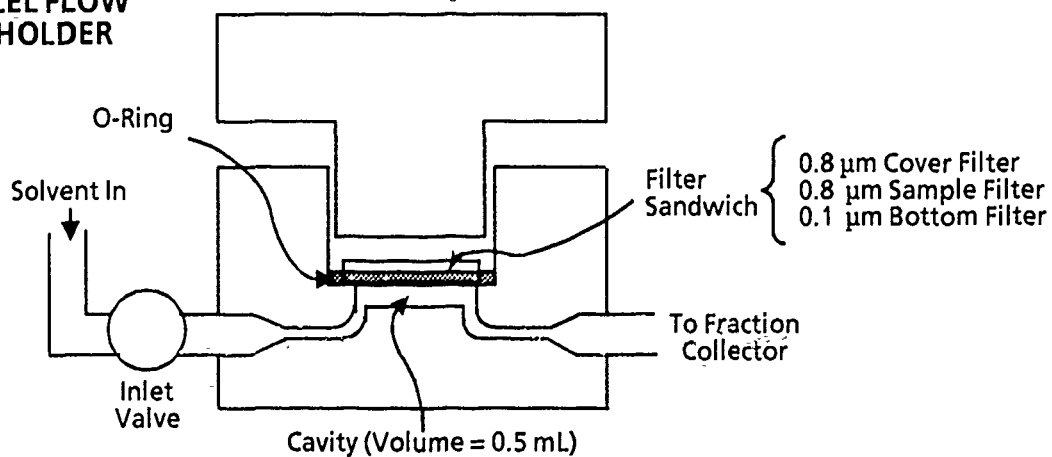


Figure 1. Experimental Apparatus Used for Determination of Particle Dissolution Kinetics.

TABLE 1. COMPOSITION OF BLOOD PLASMA AND LUNG FLUID SIMULANT

Chemical Species	Blood Plasma (mM/L)					Serum Ultrafiltrate ^a (mM/L)		
Sodium	142.0					145.0		
Potassium	5.0					-		
Calcium	2.5					0.2		
Magnesium	1.5					-		
Ammonium	-					10.0		
Protein	6.0					-		
Chloride	103.0					126.0		
Bicarbonate	27.0					27.0		
Phosphate	1.2					1.2		
Citrate (Cit)	0.2					0.2		
Organic Acid (peptide)	6.0					6.0		
Sulfate	0.5					0.5		
Chemical Compound ^b	NaCl	NH ₄ Cl	NaHCO ₃	NaH ₂ PO ₄ 0.2 H ₂ O	Na ₃ Cit 0.2 H ₂ O	Glycine	H ₂ SO ₄	CaCl ₂
(mM/L)	116	10	27	1.1	0.2	6.0	0.5	0.2

^a SUF = lung fluid stimulant

^b Compounds used to produce SUF

SECTION 3

RESULTS

BeO AND RME CHEMICAL COMPOSITION

Table 2 gives the analysis of trace element composition of LF and HF BeO samples as provided by the supplier. The Sp of the LF and HF BeO samples were 56.9 and 1.1 m²/g, respectively (Brush Wellman Inc., Elmore, OH). The LF and HF BeO samples were 98.5 and 99.8% pure BeO, respectively. The only remarkable difference between the two materials was an eightfold greater concentration of Aluminum (Al) and Silicon (Si) in the HF BeO, neither of which was greater than 0.16% of the total composition. Tables 3 and 4 show the trace element composition of 10 RME samples as determined by SSMS and AA, respectively. (Note: for future reference, RME samples # 6 and 8 were excluded from the pooled RME used for additional studies described herein.) As shown in Table 4 the relative amount of Be in the RME samples ranged from 16 to 25% corresponding to 44.4 to 69.4% BeO by mass. Adjusting for the relative mass contribution of the pooled RME sample, the pooled RME was 53.7% BeO by weight. As might be expected, trace element composition (where comparable on an element by element basis) in the RME was much greater than in the either LF or HF BeO. With respect to Al composition RME was similar to LF BeO. Silicon composition of the RME particles was at an intermediate level between LF and HF BeO.

PARTICLE MORPHOLOGY

The results of size distribution analysis and calculations, BET determination of Sp and pycnometric determination of absolute density of the test material particles after pulverization are given in Table 5. The pulverization process reduced particle size dramatically from CMDs exceeding 300 µm to CMDs of 0.14, 1.45 and 0.16 µm for LF, HF BeO, and RME, respectively. With respect to MMAD, the LF BeO and RME are both well within the respirable size range and were optimal for pulmonary deposition. Although the pulverization process was identical for all materials, the HF BeO particles remained relatively large regardless of additional processing time. Nevertheless, the HF BeO particle MMAD was at the upper limit of what is considered respirable by American Conference of Government Industrial Hygienists (ACGIH) standards. The pulverization process apparently did not affect the Sp of the BeO samples. The Sp of LF BeO post- versus prepulverization was 50.4 m²/g compared to 56.9 m²/g. HF BeO post- versus prepulverization Sps were 1.3 and 1.1 m²/g, respectively. As shown in Figure 2, the LF BeO and RME particles were the most physically similar, with regard to size and shape, both appeared micellar and nearly spherical; whereas, HF BeO particles were unaggregated and platyform.

TABLE 2. TRACE ELEMENT COMPOSITION OF LOW- AND HIGH-TEMPERATURE CALCINED BeO

Element	550 °C	1600 °C
Boron	2 ppm	1 ppm
Aluminum	40 ppm	320 ppm
Chromium	2 ppm	2 ppm
Iron	10 ppm	15 ppm
Magnesium	5 ppm	5 ppm
Manganese	2 ppm	2 ppm
Nickel	3 ppm	3 ppm
Titanium	4 ppm	4 ppm
Sodium	30 ppm	60 ppm
Silver	1 ppm	1 ppm
Calcium	30 ppm	30 ppm
Cobalt	1 ppm	1 ppm
Copper	2 ppm	2 ppm
Molybdenum	3 ppm	3 ppm
Lead	2 ppm	2 ppm
Silicon	195 ppm	1150 ppm
Zinc	20 ppm	20 ppm
Uranium	30 ppm	40 ppm
Fluorine	1.46%	n.d.

ppm = Parts per million (wt/wt)

n.d. = Not detected

TABLE 3. ELEMENTAL COMPOSITION OF RME PARTICLE SAMPLES BY SSMS

Sample No.	Element ^a						
	B	Si	P	Cl	K	Fe	Mn
1	>4100	1100	290	210	190	3900	240
2	>4100	280	1000	1100	230	>1%	2500
3	>4100	100	820	1100	1100	>1%	98
4	2000	70	190	1400	1%	3600	150
5	2000	100	1100	650	940	3600	49
6	1600	280	680	280	400	>1%	2800
7	2000	420	680	620	270	>1%	1300
8	>4100	600	1400	280	230	>1%	2000
9	>4100	600	680	740	>1%	>1%	4%
10	>4100	420	1400	2800	53	>1%	660

^a Parts per million (wt/wt) unless otherwise specified

TABLE 4. ELEMENTAL COMPOSITION OF RME PARTICLE
SAMPLES BY AA

Sample No.	Element ^a		
	Be	Al	Mg
1	170,000 (17%)	130	330
2	170,000 (17%)	130	400
3	230,000 (23%)	120	270
4	200,000 (20%)	200	1300
5	250,000 (25%)	140	220
6	68,000 (6.8%)	110	120
7	160,000 (16%)	110	340
8	160,000 (16%)	210	100
9	190,000 (19%)	140	860
10	220,000 (22%)	170	200

^a Parts per million (wt/wt) unless otherwise specified

TABLE 5. PARTICLE MORPHOLOGY

	CMD (μm)	MMD (μm)	MMAD (μm)	σ_g	Specific Surface Area (m^2/g)	Density (g/cm^3)
LF BeO	0.14	1.15	1.88	2.36	50.4	2.67
HF BeO	1.45	6.00	10.60	1.99	1.3	3.12
RME	0.16	0.72	1.37	2.02	31.8	3.61

CMD = Count Median Diameter

MMD = Mass Median Diameter

MMAD = Mass Median Aerodynamic Diameter

σ_g = Geometric Standard Deviation



Figure 2. Electron Photomicrographs of LF BeO, RME, and HF BeO Particles.

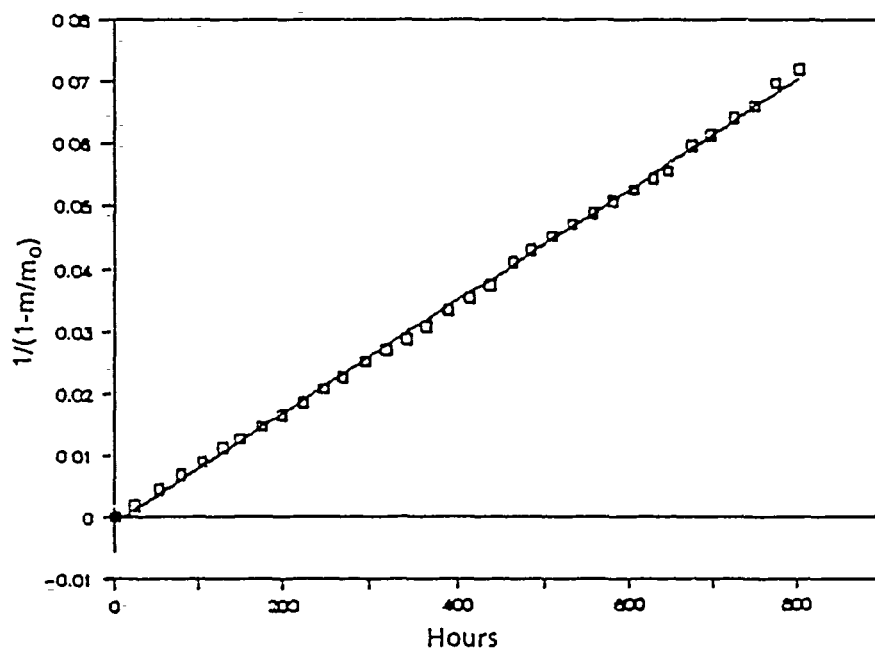
DISSOLUTION KINETICS

The mass fraction of Be, hence BeO, dissolved from each test material (calculated as the inverse of $1 - M/M_0$, where M is the remaining mass and M_0 is the initial sample mass) was plotted as a function of time for each of the filter samples (Figures 3 to 5). Regression analysis proved the curves to be linear thus fitting a simple line of the form $y = mx + b$, with the slope, m , corresponding to the fractional dissolution rate per unit time. The fractional dissolution rate was then normalized by division of m by the respective material S_p to give the dissolution rate constant k , which has been shown by Mercer (1967) to be a major determinant by which relatively insoluble aerosol particles are cleared from the lung. The relationship is as follows.

$$k (g/cm^2/t) = m (g/t)/S_p (cm^2/g)$$

Respective values of m and k for each of the filter samples are given in Table 6. The fractional dissolution rate, m , in SUF, for LF and HF BeO was found to agree with coefficients reported by other investigators (Finch et al., 1988b). The average m for LF and HF BeO of 2.3×10^{-3} and 2.4×10^{-3} found in this investigation compared well with corresponding values determined from data previously reported – 3.2×10^{-3} and 1.7×10^{-3} . The mean dissolution rate constant, k , for LF BeO also was found to be in agreement with that reported by these investigators (4.56×10^{-9} and 2.2×10^{-9} , respectively). However, we found a much larger k for HF BeO (1.87×10^{-7}) than that reported by these investigators (3.7×10^{-9}). This discrepancy can be accounted for by the 35-fold difference between the S_p of HF BeO in the present study and the study by Finch and colleagues (1.3 vs. 44.5 m^2/g). Also the HF BeO investigated by these researchers was calcined at 1000 °C versus the 1600 °C calcination temperature of the HF BeO used in the present investigation.

Low Fired BeO No. 1



Low Fired BeO No. 2

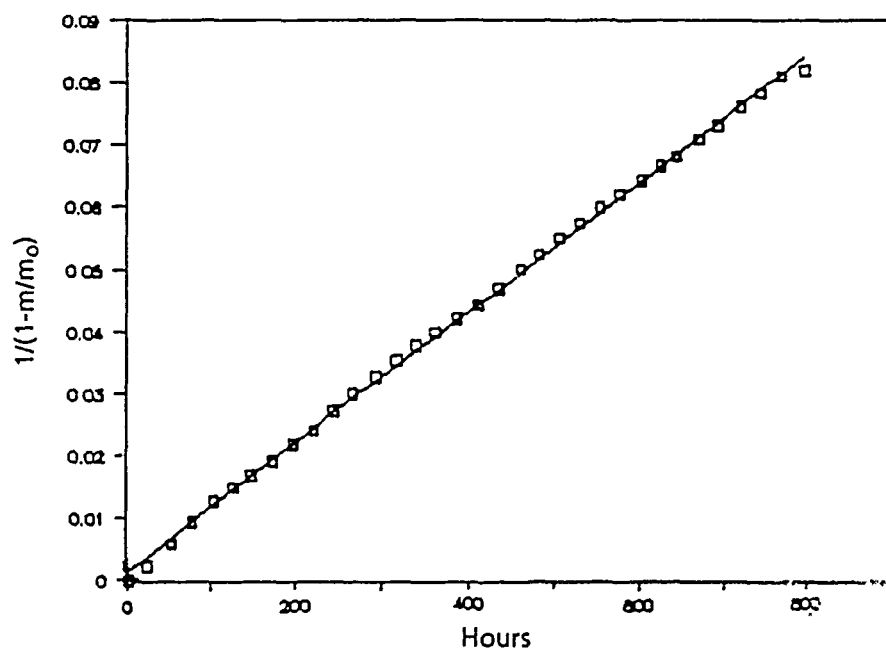
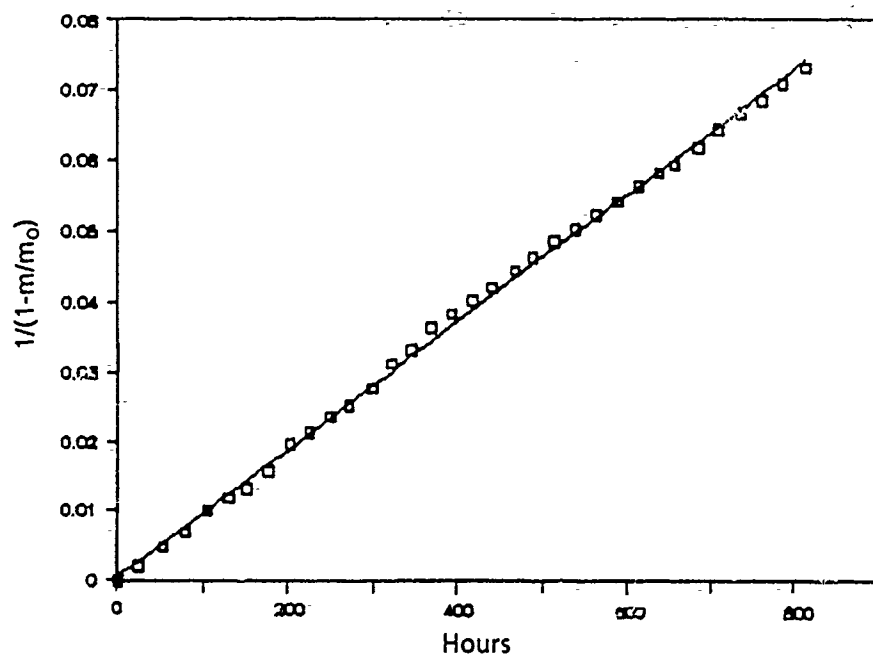


Figure 3. Time Course of Fractional (Cumulative) Dissolution of LF BeO in SUF: Two Samples.

High Fired BeO No. 1



High Fired BeO No. 2

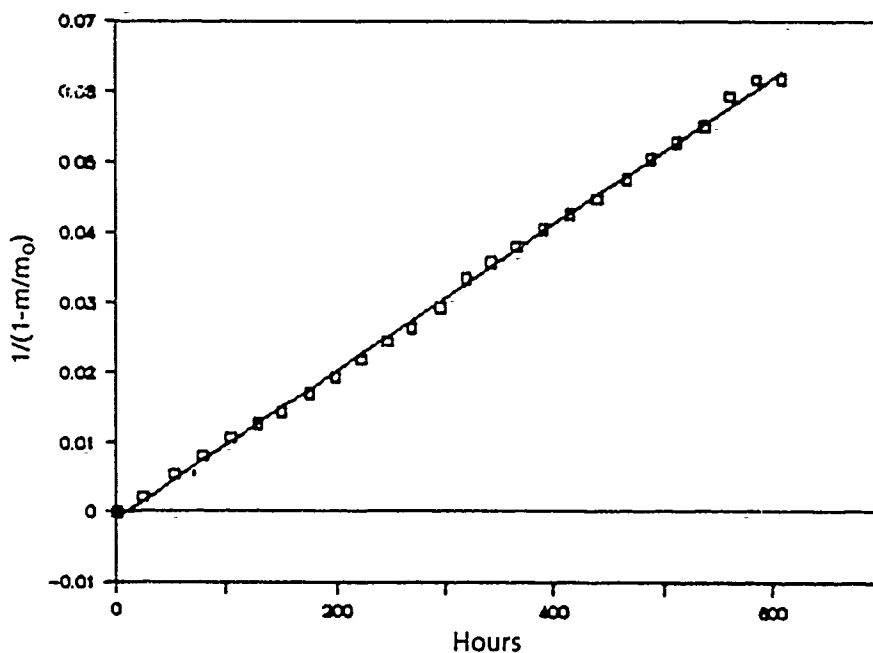


Figure 4. Time Course of Fractional (Cumulative) Dissolution of HF BeO in SUF: Two Samples.

Rocket Exhaust BeO No. 1

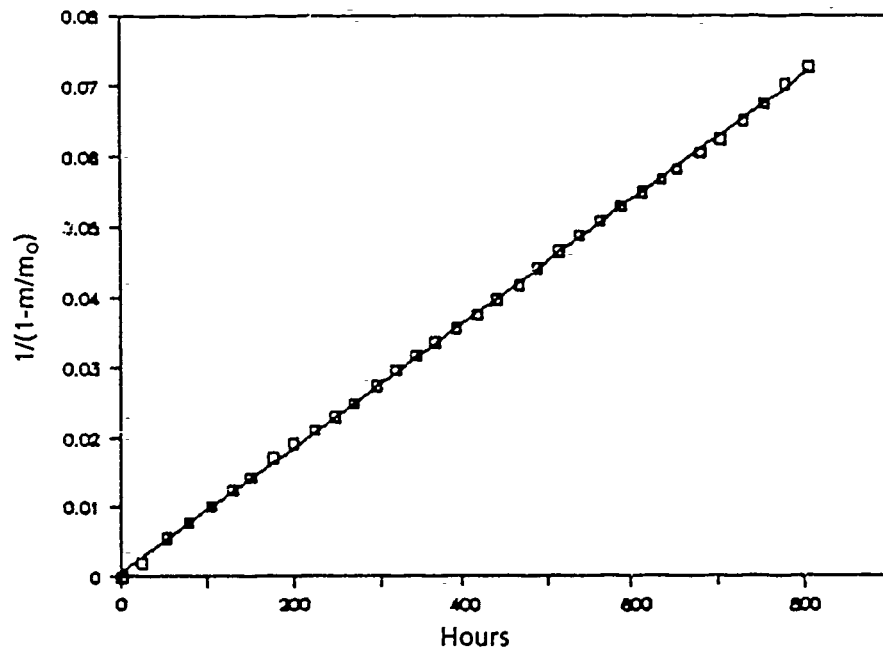


Figure 5. Time Course of Fractional (Cumulative) Dissolution of RME in SUF: Single Samples.

TABLE 6. PARTICLE DISSOLUTION KINETICS

	m (g/day)	k (g/cm ² /day)
LF BeO 1	2.13 x 10 ⁻³	4.22 x 10 ⁻⁹
LF BeO 2	2.43 x 10 ⁻³	4.82 x 10 ⁻⁹
HF BeO 1	2.33 x 10 ⁻³	1.79 x 10 ⁻⁷
HF BeO 2	2.53 x 10 ⁻³	1.95 x 10 ⁻⁷
RME	2.14 x 10 ⁻³	6.95 x 10 ⁻⁹

m = Fractional dissolution rate

k = Dissolution rate constant

SECTION 4

DISCUSSION

Conventional logic suggests that BeO calcined at higher temperatures should be most similar to BeO formed during the firing of a rocket motor. Comparison of the trace element analyses of RME and the two forms of BeO does not suggest a similarity of RME to either form. The particle morphology, Sp, ease of pulverization, and dissolution kinetics of RME appear to be most similar to that of LF BeO, which could be due to a similarity of the crystalline structure of these materials. Discriminant classification analysis primarily based on m and k parameters with consideration of Si and Al content, demonstrated that, statistically, RME was significantly similar to LF BeO. Consequently, these observations imply that the relative potential toxicity of RME may be most similar to that of LF BeO; if RME cannot be readily obtained for any further investigations, LF BeO may be the most suitable surrogate material to use. However, it is important to note that the RME used in this experiment was not collected *in situ* and therefore may not be physically or chemically representative of BeO-laden RME as it exists in the atmosphere.

REFERENCES

- Callahan, M.A. 1979. *Water Related Environmental Fate of 129 Priority Pollutants, Literature Search II, Metals and Organics*. Washington, DC: Environmental Protection Agency, Office of Water Planning and Standards.
- Carpenter, R.L., K.L. Yerkes, E.C. Kimmel, A. Vinegar, C.D. Flemming, and W.R. Sayers. 1989. Methods for generating and studying aerosol dissolution properties: BeO containing rocket exhaust particles. In: R.S. Kutzman and R.B. Conolly, eds. *1988 Toxic Hazards Research Unit Annual Report*. AAMRL-TR-89-022. Wright-Patterson Air Force Base, OH: Harry G. Armstrong Aerospace Medical Research Laboratory. NMRI-89-36. Bethesda, MD: Naval Medical Research Institute.
- Eidson, A.F., M.D. Hoover, B.J. Greenspan, and C.A. Cornell. 1984. Characteristics of beryllium aerosols for toxicity studies. In: *Inhalation Toxicology Research Institute Annual Report*. LMF-113. Albuquerque, NM.
- Finch, G.L., J.A. Mewhinney, A.F. Eidson, M.D. Hoover, and S.J. Rothenberg. 1988a. In vitro dissolution characteristics of beryllium oxide and beryllium metal aerosols. *J. Aerosol Sci.* 19: 333-342.
- Finch, G.L., A.L. Brooks, M.D. Hoover, and R.G. Cuddihy. 1988b. Influence of physicochemical properties of beryllium particles on toxicity of cultured cells. *In Vitro Toxicol.* 2: 287-297.
- Hardy, H.L., and I.R. Tabershaw. 1946. Delayed chemical pneumonitis occurring in workers exposed to beryllium compounds. *J. Ind. Hyg. Toxicol.* 28: 197-211.
- Hart, B.A., A.G. Harmsen, R.B. Low, and R. Emerson. 1984. Biochemical, cytological and histological alterations in rat lung following acute beryllium aerosol exposure. *Toxicol. Appl. Pharmacol.* 75: 454-465.
- Hatch, T., and S.P. Choate. 1929. Statistical description of the size properties of non-uniform particulate substances. *J. Franklin Inst.* 207: 369-387.
- Hinds, W.C. 1982. *Aerosol Technology: Properties, Behavior and Measurement of Airborne Particles*. New York, NY: John Wiley and Sons, Inc.
- Johnson, R.A., and D.W. Wichern. 1988. *Applied Multivariate Statistical Analysis*. Englewood Cliffs, NJ: Prentice-Hall, Inc.
- Mercer, T.T. 1967. On the role of particle size in the dissolution of lung burdens. *Health Phys.* 13: 1211-1221.
- Moss, O.R., and G.M. Kanapilly. 1980. Dissolution of inhaled aerosols. In: K. Willeke, ed. *Generation of Aerosols and Facilities for Exposure Experiments*. Ann Arbor, MI: Ann Arbor Science Publishers, Inc.
- Rauo, O.G. 1970. Generation and characterization of aerosols. In: *Inhalation Carcinogenesis*. Proceedings of the Biology Division, Oak Ridge National Laboratory Conference, CONF-691001, Gatlinburg, TN, October 8-11, 1969.
- Rothenberg, S.J., P.B. DeNee, Y.S. Cheng, R.L. Hanson, H.C. Yeh, and A.F. Eidson. 1982. Methods for the measurement of surface areas of aerosols by absorption. *Adv. Coll. and Int. Sci.* 15: 223-249.

Sanders, C.L., W.C. Cannon, G.J. Powers, R.R. Adey, and D.M. Meier. 1975. Toxicology of high-fired beryllium oxide inhaled by rodents. *Arch. Environ. Health*. 30: 546-551.

Spencer, H.C., R.H. Hook, J.A. Blumenshine, S.B. McCollister, S.E. Sadek, and J.C. Jones. 1968. Toxicological studies on beryllium-containing exhaust products. AAMRL-TR-68-148. Wright-Patterson Air Force Base, OH: Harry G. Armstrong Aerospace Medical Research Laboratory.

Taylor, M.L., and E.L. Arnold. 1969. Beryllium analysis by gas chromatography. AAMRL-TR-69-130. Wright-Patterson Air Force Base, OH: Harry G. Armstrong Aerospace Medical Research Laboratory.

Wagoner, J.K., P.F. Infante, and D.L. Bayliss. 1980. Beryllium: An etiologic agent in the induction of lung cancer, nonneoplastic respiratory disease and heart disease among industrially exposed workers. *Environ. Res.* 21: 15-34.

Willeke, K., and P.A. Baron. 1990. Sampling and interpretation errors in aerosol monitoring. *Am. Ind. Hyg. Assoc. J.* 51: 160-168.

QUALITY ASSURANCE

The study, "Physicochemical Properties and Dissolution in Simulated Biological Fluids of Particles of Beryllium Powered Rocket Motor Exhaust and Pure Beryllium Oxides Calcined At Low and High Temperature," was conducted by the NSI Technology Services Corporation, Toxic Hazards Research Unit under the guidance of the Environmental Protection Agency's Good Laboratory Practices Guidelines, 40CFR PART 792. No claim will be made that this was a "GLP" study as no attempt was made to adhere to the strict requirements of these guidelines. The various phases of this study were inspected by members of the Quality Assurance Unit. Results of these inspections were reported directly to the Study Director at the close of each inspection.

DATE OF INSPECTION:

February 13, 1989

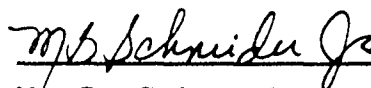
November 6-20, 1990

ITEM INSPECTED:

BeO solubility data.

Final report audit.

The Quality Assurance Unit has determined by review process that this report accurately describes those methods and standard operating procedures required by the protocol and that the reported results accurately reflect the raw data obtained during the course of the study. No discrepancies were found that would alter the interpretation presented in this Final Report.



M. G. Schneider
QA Coordinator
Toxic Hazards Research Unit

Date 28 NOV 90